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PREDICTING AND EXPLAINING THE MOVEMENT OF MESOSCALE OCEANOGRAPHIC FEATURES USING CLIPS

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ABSTRACT

The Naval Research Laboratory has developed an oceanographic expert system that describes the evolution of mesoscale features in the Gulf Stream region of the northwest Atlantic Ocean. These features include the Gulf Stream current and the warm and cold core eddies associated with the Gulf Stream. An explanation capability was added to the eddy prediction component of the expert system in order to allow the system to justify the reasoning process it uses to make predictions. The eddy prediction and explanation components of the system have recently been redesigned and translated from OPS83 to C and CLIPS and the new system is called WATE (Where Are Those Eddies). The new design has improved the system's readability, understandability and maintainability and will also allow the system to be incorporated into the Semi-Automated Mesoscale Analysis System which will eventually be embedded into the Navy's Tactical Environmental Support System, Third Generation, TESS(3).

INTRODUCTION

One of the major reasons CLIPS is so widely used is the ease with which it allows a rule base to be incorporated as one component of a larger system. This has certainly been the case with the eddy prediction component of the Semi-Automated Mesoscale Analysis System (SAMAS) (3). SAMAS is an image analysis system developed by the Naval Research Laboratory that includes a variety of image analysis tools that enable the detection of mesoscale oceanographic features in satellite images. Unfortunately, in the North Atlantic, many of the images are obscured by cloud cover for lengthy periods of time. A hybrid system for use when features cannot be detected in images has been developed that consists of a neural network that predicts movement of the Gulf Stream and a rule base that predicts movement of eddies associated with the Gulf Stream. The Gulf Stream and eddy prediction components were both originally implemented in OPS83 (4). The Gulf Stream Prediction Module has been replaced by a neural network (3) and an explanation component has recently been added to the OPS83 version of the eddy prediction component (1). The eddy prediction rule base, WATE (Where Are Those Eddies), has been translated to CLIPS because of the ease of integrating a CLIPS rule base into a larger system, the ability to access routines written in C from CLIPS rules, and the support CLIPS provides for the forward chaining reasoning used by the eddy prediction system. The explanation component of WATE uses meta rules written in CLIPS to compose either rule traces or summary explanations of the predicted movement of eddies.

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SYSTEM ARCHITECTURE

External Interfaces

The WATE component interacts with other SAMAS components as shown in Figure 1. WATE interacts with the User Interface in two ways. First, WATE is invoked from the User Interface when the user requests a prediction of Gulf Stream and eddy movement for a specified time. Second, as WATE predicts the movement of the Gulf Stream by calling the Gulf Stream Prediction Module and eddies by running the rule base, WATE calls User Interface routines to update the graphical display of the positions of the Gulf Stream and eddies. The eddy prediction rules call the Geometry Routines to compute distances and locations. WATE invokes the Gulf Stream Prediction Module to predict the movement of the Gulf Stream for each time step. The position of the Gulf Stream predicted by the neural network component must be accessed by the eddy prediction rule base since the movement of eddies is influenced by the position of the Gulf Stream.

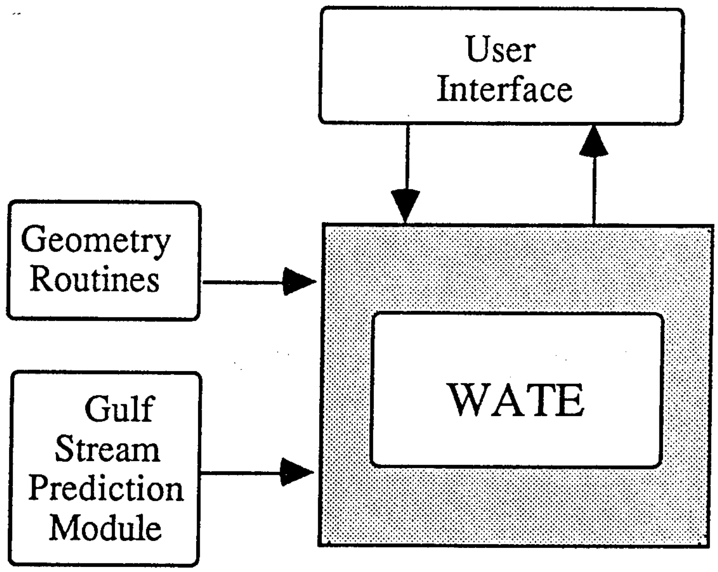

Figure 1. External Interfaces of WATE

Redesigned Control Structure

The control structure for the original expert system was written in procedural OPS code and had been modified a number of times as the graphical user interface, eddy prediction, Gulf Stream prediction, and explanation components were either modified or added. The result was a control structure that was not modular and that contained a substantial number of obsolete variables and statements. When the system was converted from OPS83, the control structure was completely redesigned and rewritten in C. Pseudo code for the redesigned control structure is shown in Figure 2. The resulting code was more efficient because it was written in compiled C code rather than interpreted OPS83 procedural code.

```
Initialization
        GetUserOptions
        SetUpCLIPS
```

```
SetUpPVWave
SetUpGulfStream

Prediction
    Display initial positions of GS and eddies
    for each time step do
        update time
        MoveGulfStream
        Update display of GS
        MoveEddies
        Update display of eddies

Explanation
    Explanation Composition
    Explanation Presentation

FinalOutput
```

Figure 2. Control Structure of WATE

Translation from OPS83 to CLIPS

The original OPS83 working memory elements and rules had been completely restructured to support an explanation component (1). The translation of this restructured OPS83 code into CLIPS was fairly simple since CLIPS has evolved from the OPS line. There is a very straightforward translation from OPS83 working memory elements to CLIPS fact templates and from OPS rules to CLIPS rules. In some cases, the OPS83 rules called OPS83 functions or procedures. These functions and procedures were translated to C.

EXPLANATION COMPONENT

The explanation component allows the user to ask for either a rule trace or summary explanation for the prediction of the movement of each eddy at the end of each prediction cycle. The rule trace explanations give a detailed trace of the instantiation of all rules that were fired to predict the movement of an eddy. Although this type of trace has proven to be very useful in debugging the system, it was immediately apparent that it contained a great deal of information that would be of little interest to most users. Interviews with domain experts were used to determine the information that would be of most interest to a user. The types of information they identified was used to design the summary explanations. Presentation of these explanations requires that the line of reasoning of the system be captured as the rules fired and that information from this rule trace be extracted and organized for presentation to the user.

Rule Firing Capture

Capturing the rule trace for this domain in a usable form is simplified because all explanations (both trace and summary) are focused on a particular eddy. This means that all of the rule-firings pertaining to the movement of one eddy can be stored together and presented as one explanation. This is accomplished by asserting a *rule-fire-record* template fact for each eddy for each time step with the following deftemplate definition:

```
(deftemplate rule-fire-record
   (field ringtype
```

```
      (allowed-symbols wcr ccr))
   (field refno
      (type INTEGER))
   (field time
      (type INTEGER))
   (multifield rules-fired
      (type SYMBOL)))
```

The ringtype, eddy identifier (*refno*), and time stamp (*time*) uniquely identify each rule-fire-record. The *rules-fired* multifield is used to store a list of the names of the rules that fired to predict the movement of the eddy during this time step. Each time a rule fires as part of the prediction process for a particular eddy, the rule name is added to the end of the *rules-fired* list.

A second set of template facts is used to record the instantiation of each rule that fires. Each time a rule fires, a *values-for-explanation* template fact is asserted which gives the value bound to each variable when the rule was fired. The deftemplate definition for *values-for-explanation* is:

```
(deftemplate values-for-explanation
   (field rule-name
      (type SYMBOL))
   (field ringtype
      (allowed-symbols wcr ccr))
   (field refno
      (type INTEGER))
   (field time
      (type INTEGER))
   (multifield var-val
      (type SYMBOL)))
```

This template contains slots for the rule name, the eddy identifier and type, and the time stamp. In addition, it contains a multifield slot whose value is a sequence of variable value pairs that gives the name of each variable used in the rule-firing and the value bound to that variable when the rule fired. This approach can be used in this domain because a single rule will never fire more than one time for a particular eddy during one time step, and all slots in templates used by the eddy prediction rules are single value. The records of the rules that fired for a particular eddy are used by meta rules to produce the explanations.

Explanation Construction and Presentation

If the user requests an explanation for a specific eddy, a set of explanation meta rules are used to construct an explanation for the predicted movement of an eddy. The user may request either a rule-trace explanation or a summary explanation. When the user makes the request, a sequence of *explain-eddy* facts for that eddy are asserted each with a progressively higher time stamp. The fact template for an *explain-eddy* fact is:

```
(explain-eddy  ccr | wcr  <ref-no>  <time>  summary | rule-trace).
```

The presence of this fact causes the *explain-single-eddy* rule to fire one time for each rule that fired to predict the movement of the eddy for that time step. Each *explain-single-eddy* rule firing matches a rule name from the *rules-fired* slot of the *rule-fire-record* with a *values-for-explanation* template for that eddy type, number, and time stamp. A *fill-template* fact is then asserted into working memory which contains all of the information needed to explain that rule firing--either in rule-trace or summary form. For each rule, there are two explanation meta rules. The first is used when a rule-trace has been requested and is a natural language translation of the rule. It will give the value of all variables used in the rule instantiation. The second is used when

a summary has been requested. It gives a much shorter summary of the actions of the rule. A few rules that are used to control the sequence of rule-firing produce no text for a summary explanation. When an explanation metarule fires, it causes a natural language translation of the rule to be sent to the user interface for presentation to the user.

The user may request an explanation of the movement of all eddies instead of just a single eddy. In this case, the process above is simply repeated for each eddy.

SUMMARY AND FUTURE WORK

WATE has been successfully converted from OPS83 to C and CLIPS. This conversion will facilitate the incorporation of WATE into SAMAS 1.2 which will eventually be embedded in TESS(3). The modular control structure of WATE is easier to understand and maintain than that of the previous system. The explanation component has been implemented using CLIPS metarules. This causes some additional maintenance burden since the two metarules that correspond to each rule must be modified if a rule is modified. In the present system, the *rule-fire-record* and *values-for-explanation* template facts are asserted by each individual rule. We are currently modifying the CLIPS inference engine to capture this information automatically as the rules fire.

Explanations produced by the current system have two major shortcomings. First, there is still a great deal of room for improvement in the summarization capabilities of the system. In particular, the system should be summarizing over both temporal and spatial dimensions. If an eddy's predicted movement is essentially in the same direction and speed for each time step, then all of this information should be collapsed into one explanation. Likewise, if several eddies all have similar movement over one or more time steps, this should be collapsed into a single explanation. The second shortcoming deals with the lack of explanation of the predictions of the neural network component. Some recent results reported in the literature have addressed this sort of problem.

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